

# Reaction Plane Dependent Away-side Modification and Near-side Ridge in Au+Au Collisions

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**Abstract.** STAR preliminary results of di-hadron correlations versus  $\phi_s$ , the trigger particle azimuthal angle relative to the constructed event plane are reported for mid-central Au+Au collisions and compared to central Au+Au as well as minimum bias  $d$ +Au collisions. The correlations are observed to vary with  $\phi_s$  on both the near and away side of the trigger particle. The away-side correlation evolves from single- to double-peak with increasing  $\phi_s$ . The near-side correlation is separated into ‘jet’ and ‘ridge’: the ridge is found to decrease with  $\phi_s$  while the jet remains relatively constant.

## 1. Introduction

Di-hadron correlations provide a valuable probe to study the medium created at RHIC. Their measurements have revealed strong suppression of back-to-back azimuthal correlation at high transverse momentum ( $p_T$ ) consistent with jet-quenching [1], enhancement and strong modification at low  $p_T$  suggesting strong jet-medium interactions [2], and the formation of a long range correlation in pseudorapidity—the so-called ridge [2, 3].

Moreover, high  $p_T$  di-hadron correlation study relative to the constructed event plane (EP) has shown a stronger back-to-back suppression when the trigger particle is out-of-plane than in-plane [4]. In this work, we extend this study to finer slices in  $\phi_s$ , the trigger particle azimuthal angle relative to EP and to lower associated  $p_T^{assoc}$ . The 20-60% mid-central Au+Au collisions at 200 GeV are used, and are compared to the top 5% central Au+Au as well as minimum bias  $d$ +Au collisions. The  $p_T$  ranges of the trigger and associated particles are  $0.15 < p_T^{assoc} < 3 < p_T^{trig} < 4$  GeV/ $c$ , and their pseudorapidity range is restricted to  $|\eta| < 1$ .

## 2. Analysis and Systematic Uncertainties

The di-hadron correlation structure sits atop a large flow background given by [5]

$$\frac{dN_{bgkd}^{pairs}}{d\Delta\phi} = B [1 + 2v_2v_2^R \cos(2\Delta\phi) + 2v_4v_4^R \cos(4\Delta\phi)] \quad (1)$$

where  $v_2$  and  $v_4$  are the associated particle anisotropic flow, and  $v_2^R$  and  $v_4^R$  are the average anisotropy of trigger particles within slice  $\phi_s - c < |\phi_{trig} - \Psi_{EP}| < \phi_s + c$ . The event plane angle  $\Psi_{EP}$  is constructed from particles outside the respective  $p_T$  range used in each correlation study. We consider the flow background up to the order of  $v_2 v_4$  which is about 10% of the final correlation signal. Namely,

$$v_2^R = \frac{T_2 + (1 + T_4)v_2^{trig} + (T_2 + T_6)v_4^{trig}}{1 + 2T_2v_2^{trig} + 2T_4v_4^{trig}}, \quad v_4^R = \frac{T_4 + (T_2 + T_6)v_2^{trig}}{1 + 2T_2v_2^{trig}}, \quad (2)$$

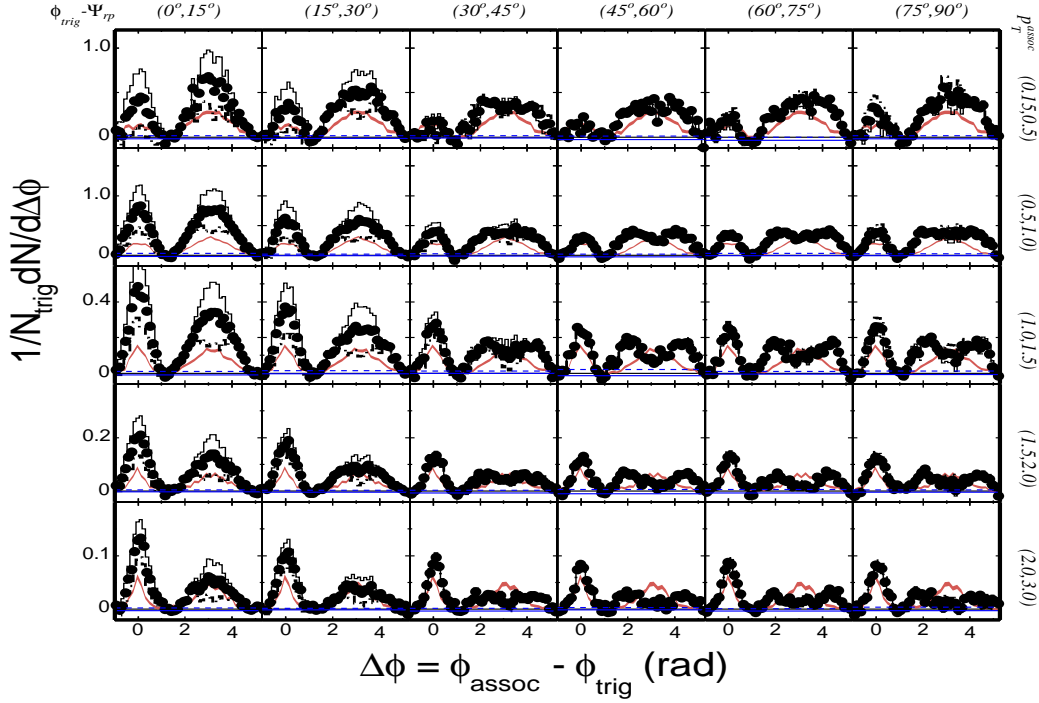
where  $T_k = \cos(k\phi_s) \frac{\sin(kc)}{kc} \langle \cos(k\Delta\Psi) \rangle$  ( $k=2,4$ ), and  $v_2^{trig}$  and  $v_4^{trig}$  are trigger particle flow.

The systematic uncertainties on our results come mainly from background subtraction which are dominated by uncertainties in the flow measurements and background normalization by  $B$  in Eq.(1). We use the average of  $v_2$  from the modified reaction plane ( $v_2\{MRP\}$ ) and the 4-particle cumulant ( $v_2\{4\}$ ) method and use the range between the two as our systematic uncertainty [2]. We use the parameterized  $v_4 = 1.15v_2^2$  for  $v_4$  values and the error calculation. We assume zero signal in the lowest  $\Delta\phi$  region of size 0.52 to obtain  $B$ . We vary the  $\Delta\phi$  size between 0.26 and 0.78 to estimate the systematic uncertainty on  $B$ .

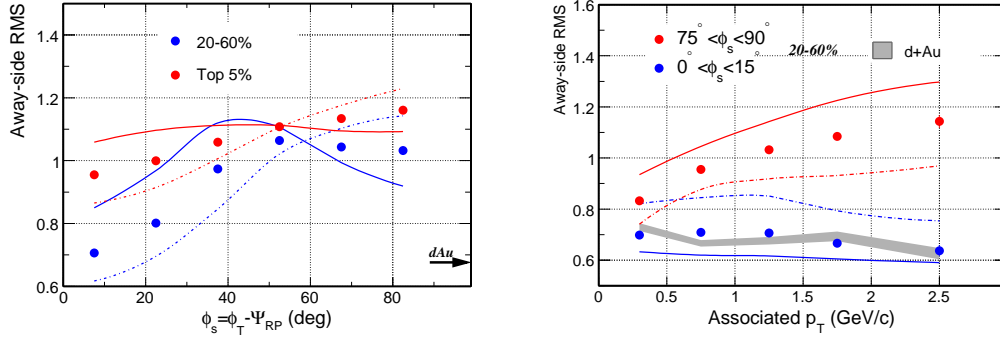
### 3. Results and Discussions

Figure 1 shows the background subtracted di-hadron correlation as a function of  $\phi_s$  and  $p_T^{assoc}$ . The away-side correlation evolves dramatically from single-peak to double-peak as  $\phi_s$  increases from in-plane ( $\phi_s \sim 0^\circ$ ) to out-of-plane ( $\phi_s \sim 90^\circ$ ) for most  $p_T^{assoc}$  bins. To quantify the away-side modification, we show in Fig. 2 (left) the RMS of the correlation function within  $|\Delta\phi - \pi| < \pi - 1$  versus  $\phi_s$  in 20-60% as well as the top 5% Au+Au data. The RMS increases with  $\phi_s$  (i.e. the away-side distribution broadens with  $\phi_s$ ); the effect is smaller in central collisions. For  $\phi_s \sim 0^\circ$  the RMS in 20-60% collisions is not much larger than in  $d+Au$ , while in 5% central collisions, it already shows a marked broadening from  $d+Au$ . This is qualitatively consistent with the different pathlengths the away-side parton traverses in the reaction plane (RP) direction for the two centralities. On the other hand, the RMS for  $\phi_s \sim 90^\circ$  are not much different between the two, again consistent with the collision geometry—the pathlengths perpendicular to RP are similar. The  $p_T^{assoc}$  dependence of the away-side RMS is shown in Fig. 2 (right) for the 20-60% centrality. The RMS remains constant over all  $p_T^{assoc}$  at small  $\phi_s$ , and increases with  $p_T^{assoc}$  at large  $\phi_s$ . The double-peak structure is stronger when the trigger particle is further away from RP and the associated particle is harder.

The shape of the near-side correlation shown in Fig. 1 remains relatively unchanged, while the amplitude drops with  $\phi_s$  and then appears to saturate for all  $p_T^{assoc}$ . Motivated by previous observations [2, 3], we separate the near-side correlation into ‘jet’ and ‘ridge’ by analyzing the data in two  $\Delta\eta$  regions:  $|\Delta\eta| > 0.7$  where the ridge is the dominant contributor and  $|\Delta\eta| < 0.7$  where both jet and ridge contribute. The jet part is in



**Figure 1.** Background subtracted di-hadron correlations as a function of  $\phi_s = \phi_{trig} - \Psi_{EP}$  and  $p_T^{assoc}$  for  $3 < p_T^{trig} < 4$  GeV/c in 20-60% Au+Au collisions. The  $\phi_s$  range increases from 0-15° (left column) to 75-90° (right column); the  $p_T^{assoc}$  range increases from 0.15-0.5 GeV/c (top row) to 2-3 GeV/c (bottom row). The histograms and dashed lines indicate the systematic uncertainties from flow and background normalization, respectively. The mini-bias d+Au inclusive di-hadron correlation is superimposed in red for comparison.

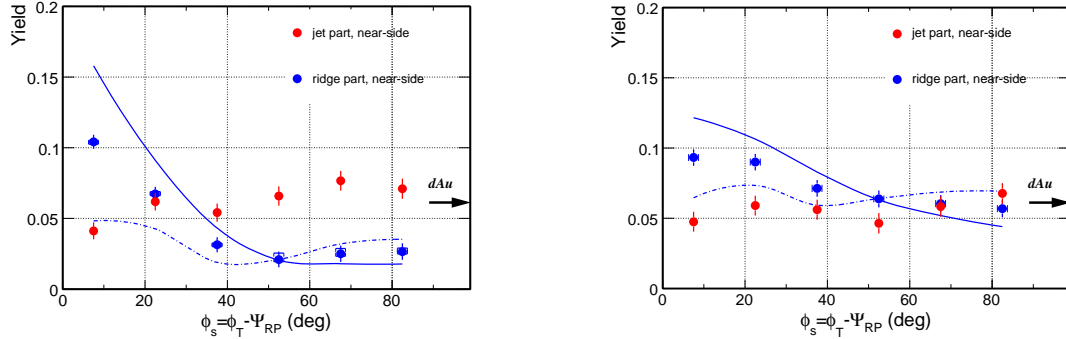


**Figure 2.** Left panel: The di-hadron correlation function away-side RMS versus  $\phi_s$  in 20-60% (blue) and top 5% (red) Au+Au collisions for  $1.0 < p_T^{assoc} < 1.5$  GeV/c. Right panel: The away-side RMS for two  $\phi_s$  slices versus  $p_T^{assoc}$  in 20-60% Au+Au collisions. The trigger  $p_T$  range is  $3 < p_T^{trig} < 4$  GeV/c for both panels. The curves indicate systematic uncertainties due to flow (solid:  $v_2\{4\}$ ; dashed:  $v_2\{MRP\}$ ). The corresponding d+Au result is indicated by the arrow and the shaded area.

turn obtained from the difference between the raw correlation in  $|\Delta\eta| < 0.7$  and that in  $|\Delta\eta| > 0.7$  scaled by the  $\Delta\eta$  acceptance factor of approximately 1.45. The systematic uncertainties due to background and flow are largely cancelled in the jet result because

flow is measured to be independent of  $\eta$  in our measured range.

Figure 3 shows the jet and ridge yields in  $|\Delta\eta| < 0.7$  and  $|\Delta\phi| < 1$  as a function of  $\phi_s$  for both 20-60% and top 5% collisions. While the jet yield remains relatively constant (or slightly increases), the ridge yield decreases with  $\phi_s$ , more significantly in the 20-60% centrality. The data indicate that the ridge is predominant only in the RP direction in mid-central collisions, presumably due to strong interactions between the near-side parton and the medium. The near-side jet perpendicular to RP, on the other hand, suffers minimal interaction, resulting in no significant ridge. The  $\phi_s$  dependence of the ridge yield in the top 5% collisions is weaker, qualitatively consistent with the more spherical collision geometry in these collisions. It is also interesting to note that the ridge yields at small  $\phi_s$  are similar between the two centralities, perhaps due to the similar surface curvature and/or gluon density in the RP direction for the two centralities.



**Figure 3.** The near-side di-hadron correlation yields in  $|\Delta\eta| < 0.7$  and  $|\Delta\phi| < 1$  for the jet part (red) and the ridge part (blue) as a function of  $\phi_s$ . The results are for  $3 < p_T^{trig} < 4$  GeV/c and  $1.5 < p_T^{assoc} < 2.0$  GeV/c in 20-60% (left) and top 5% (right) Au+Au collisions. The curves indicate systematic uncertainties (solid:  $v_2\{4\}$ , dashed:  $v_2\{RP\}$ ). The d+Au result is indicated by the arrows.

#### 4. Summary

We have reported the STAR preliminary results of di-hadron correlations as a function of  $\phi_s$ , the trigger particle azimuthal angle relative to the constructed event plane in Au+Au collisions at 200 GeV. The correlations depend on  $\phi_s$  on both the near and away side. The away-side structure in 20-60% collisions evolves from single- to double-peak with trigger particles from in-plane to out-of-plane, while the evolution is less significant in central collisions where the double-peak structure is evident already at small  $\phi_s$ . At large  $\phi_s$  no significant difference on the away side is observed between the two centralities. The away-side data suggest pathlength effect in jet-quenching.

The near side is decomposed into jet and ridge. The jet yield remains relatively constant over (or slightly increases with)  $\phi_s$ . The ridge yield is significant at small  $\phi_s$  and drops with increasing  $\phi_s$  in 20-60% Au+Au collisions. The ridge yields in the reaction plane direction are similar for the two centralities. In the direction perpendicular to the reaction plane, sizeable ridge remains in central collisions, while little ridge is observed

in 20-60% collisions. These results may suggest connection of the surface geometry and the formation to the near-side ridge.

## References

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